New results from HARP-CDP and the "LSND anomaly"

Friedrich Dydak
CERN

(friedrich.dydak@cern.ch)

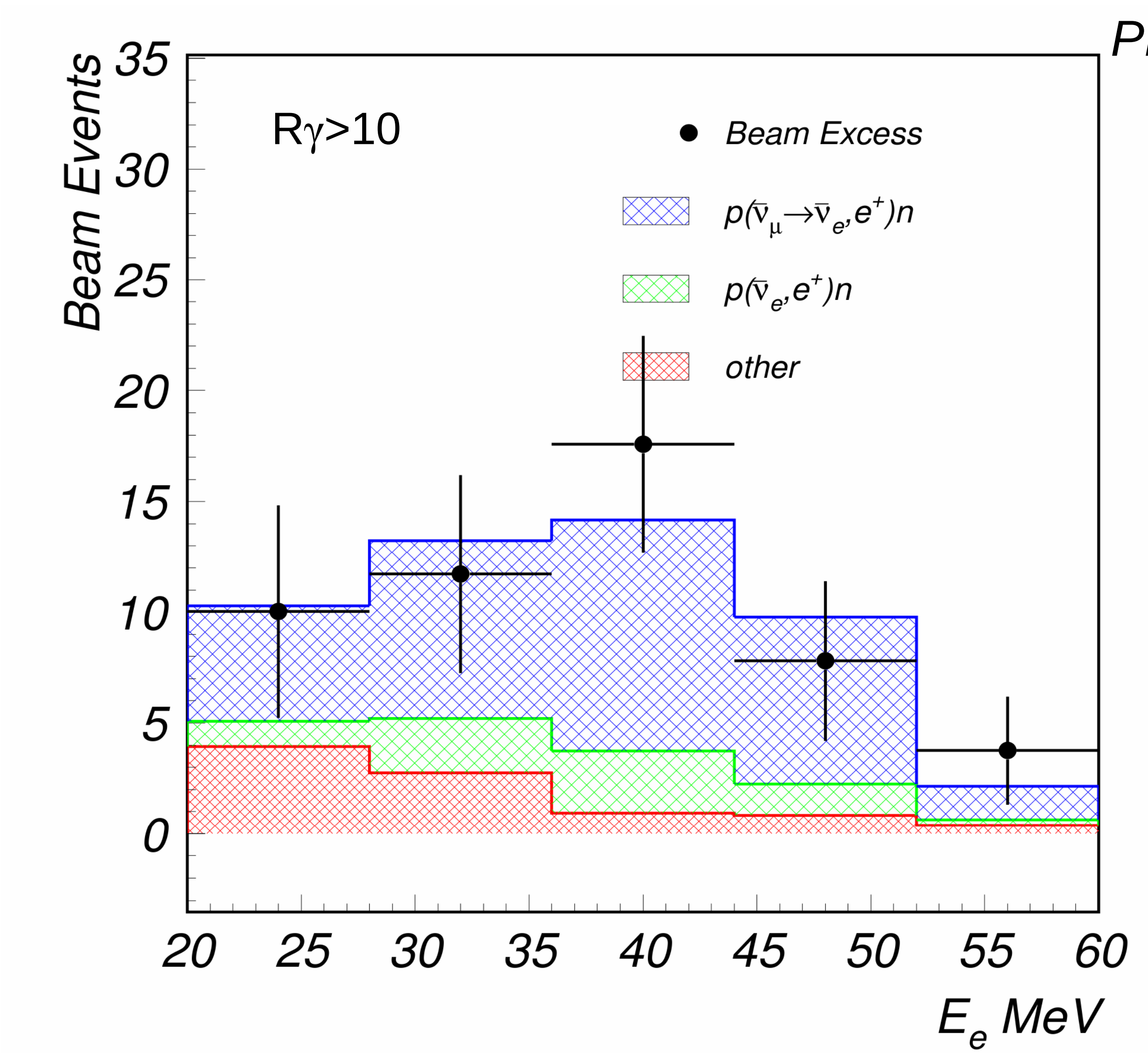
Fermilab, January 14, 2011

LSND

- Beam dump experiment in Los-Alamos
- Data taking 1993-1998
- Claimed evidence for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- This claim became known as "LSND anomaly"

The "LSND anomaly"

A. Aguilar et al., PRD64 (2001) 112007



Excess of 87.9±22.4±6.0 $\bar{\nu}_e$ events (3.8σ)

- LSND anomaly: in conflict with the measurements of solar and atmospheric neutrino oscillations

- At least one more light neutrino needed, but this contradicts LEP: $N_\nu = 2.9840 \pm 0.0082$

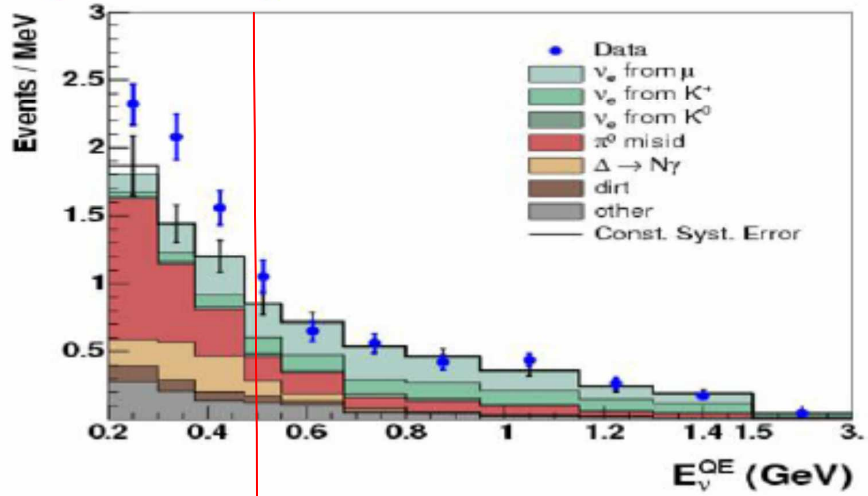
- Existence of at least one 'sterile' neutrino is required

- SPIRES: 800 theoretical papers on sterile neutrinos (700 after 1998)

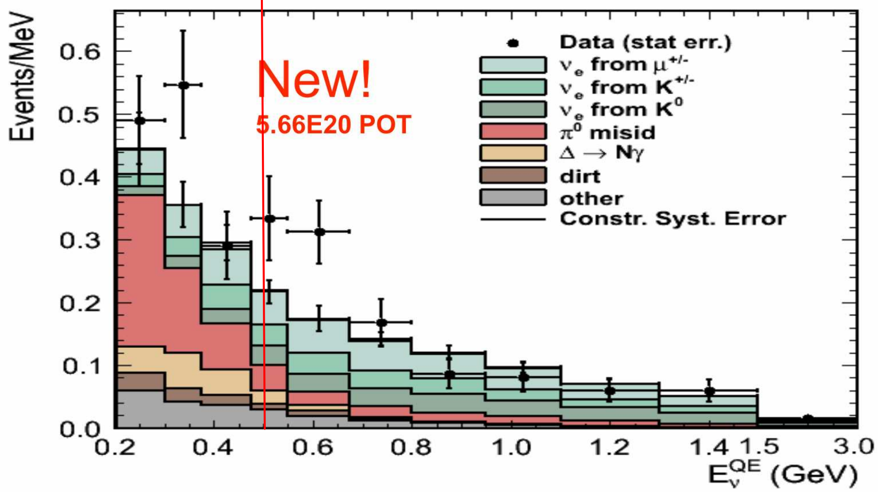
Test by MiniBooNE

MiniBooNE ν_e and $\bar{\nu}_e$ Data

ν Mode

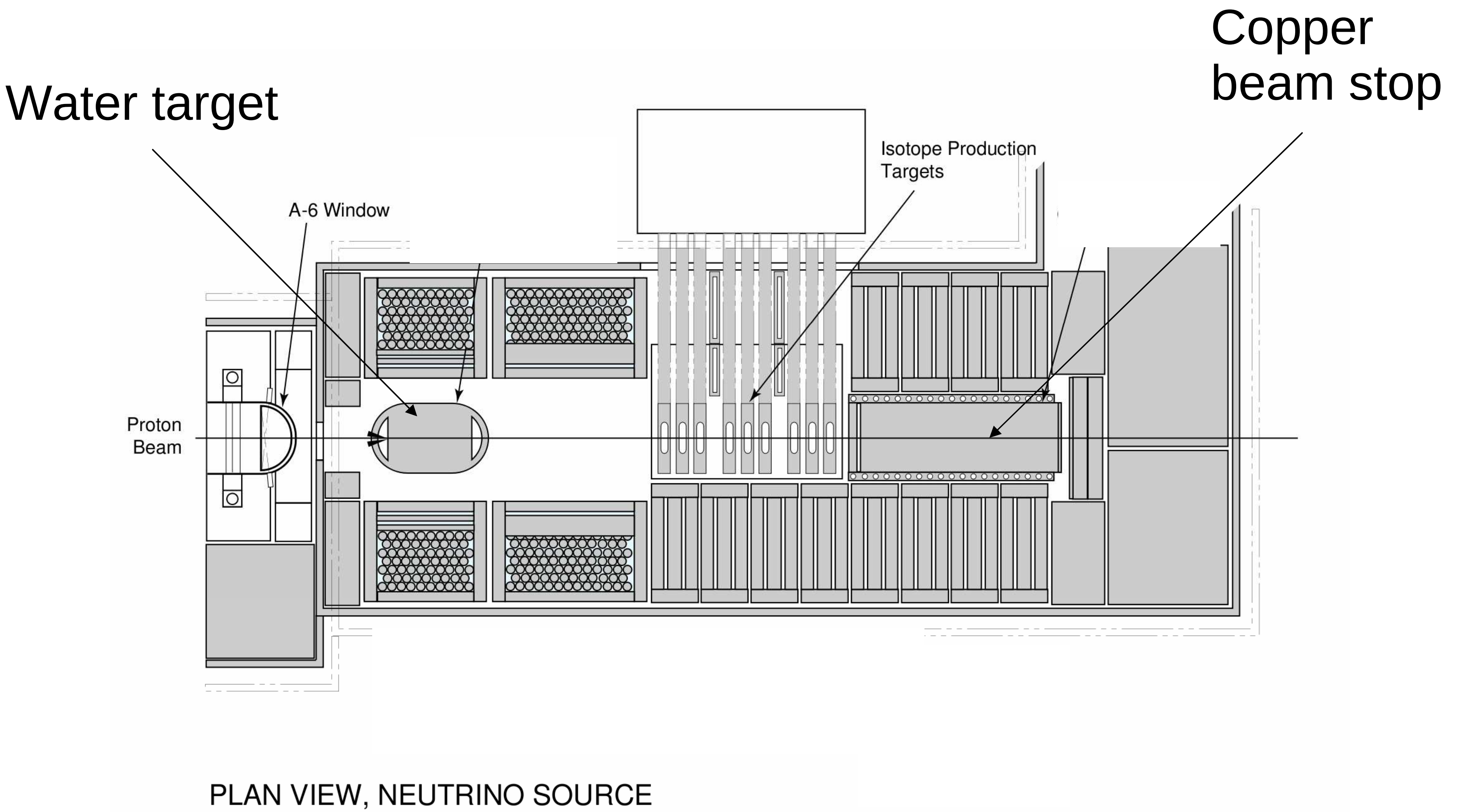


$\bar{\nu}$ Mode



G.Mills, ICHEP2010

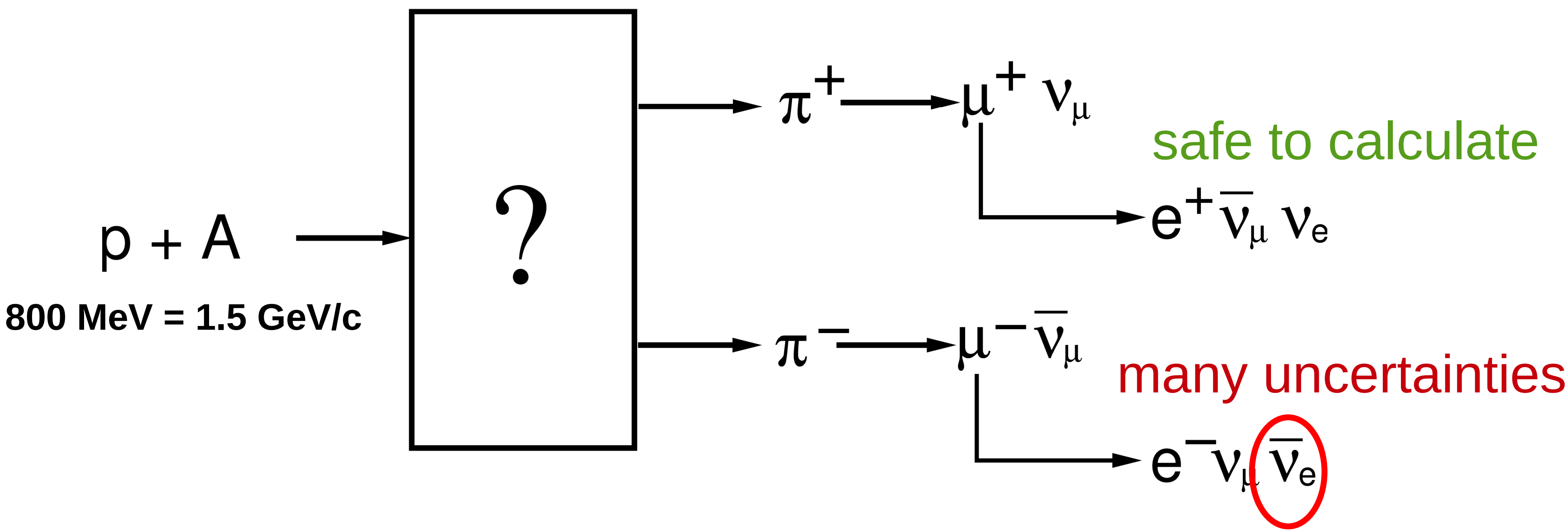
The LSND neutrino source



Geometry of 1993-1995

C.Athanassopoulos et al., NIM A388 (1997) 149-172

The LSND neutrino source



DAR = Decay at Rest

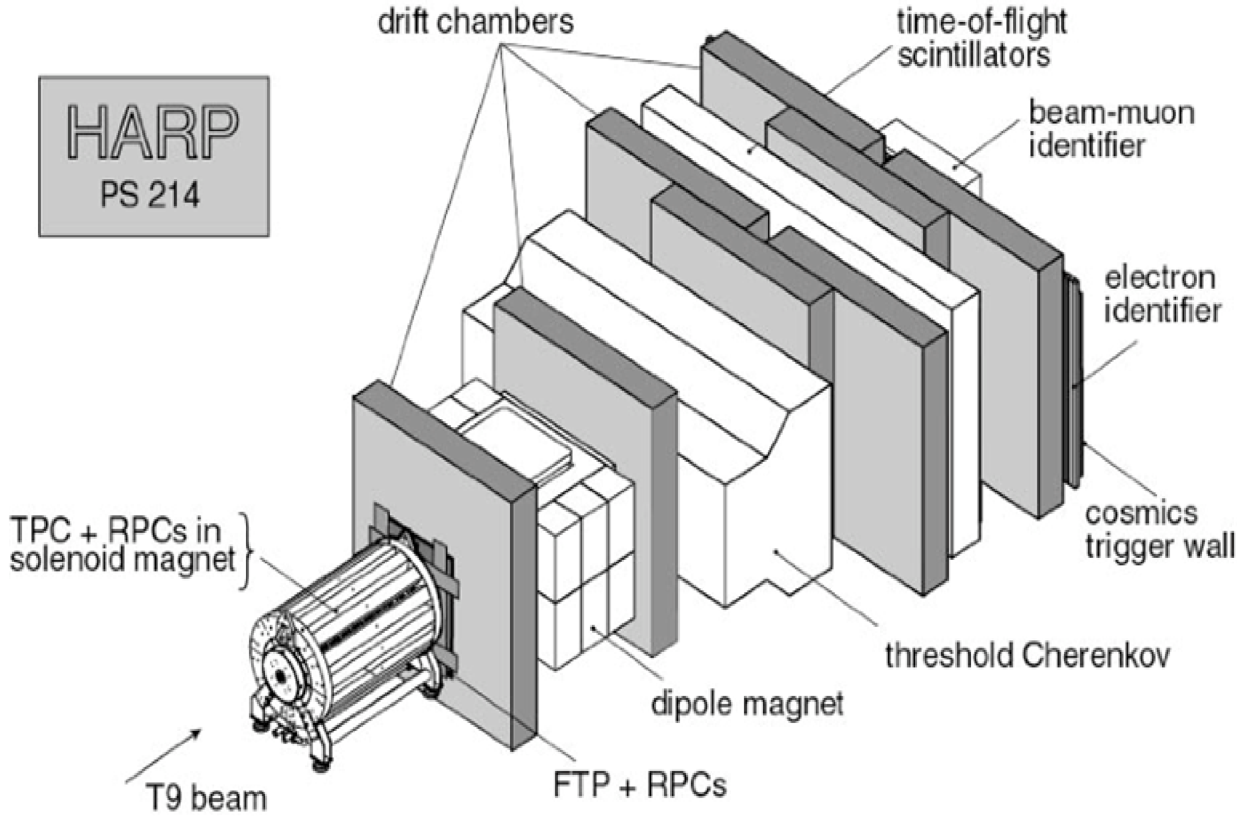
DIF = Decay in Flight

The HARP experiment (1/2)

- Proton and $\pi^{\pm}$ beams of 1.5 – 15 GeV/c
- Targets:

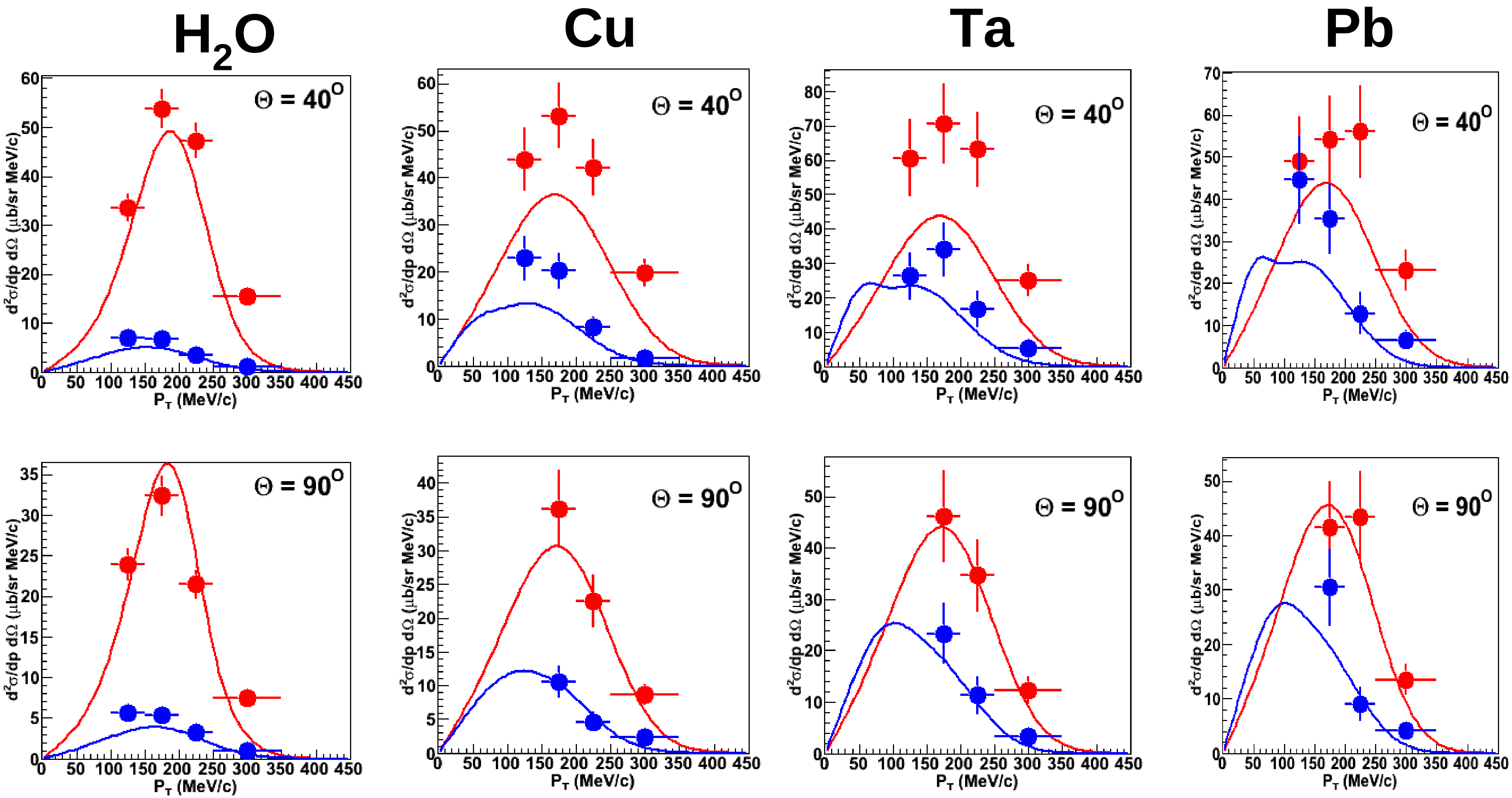
Be C Al Cu Sn Ta Pb H_2 D_2 N_2 O_2 H_2O

- Large Angle Spectrometer: $20^{o}<\theta<140^{o}$



HARP-CDP data vs LSND parametrization

$p(1.5\ \mathrm{GeV}/c) + A \rightarrow (\pi^+, \pi^-)\,X$



The HARP-CDP simulations

Two independent simulations

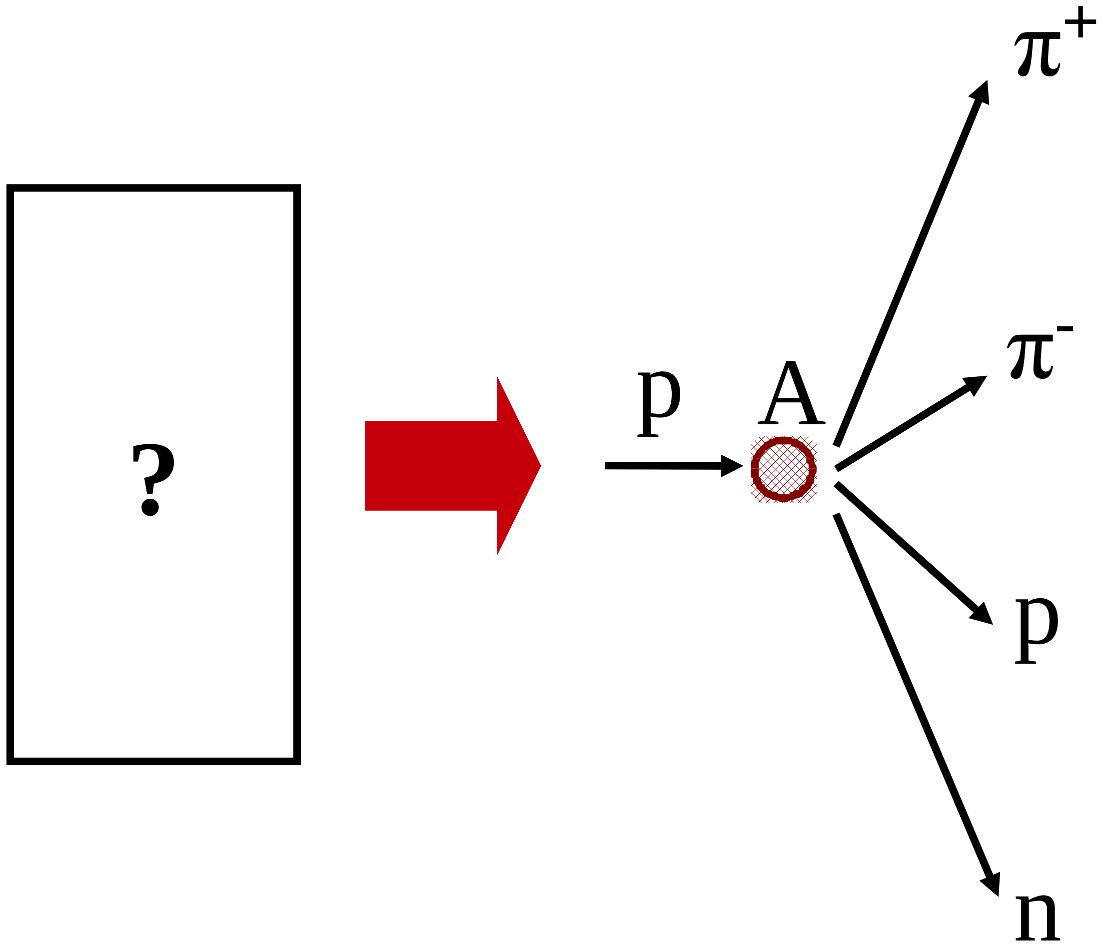
Geant4-based

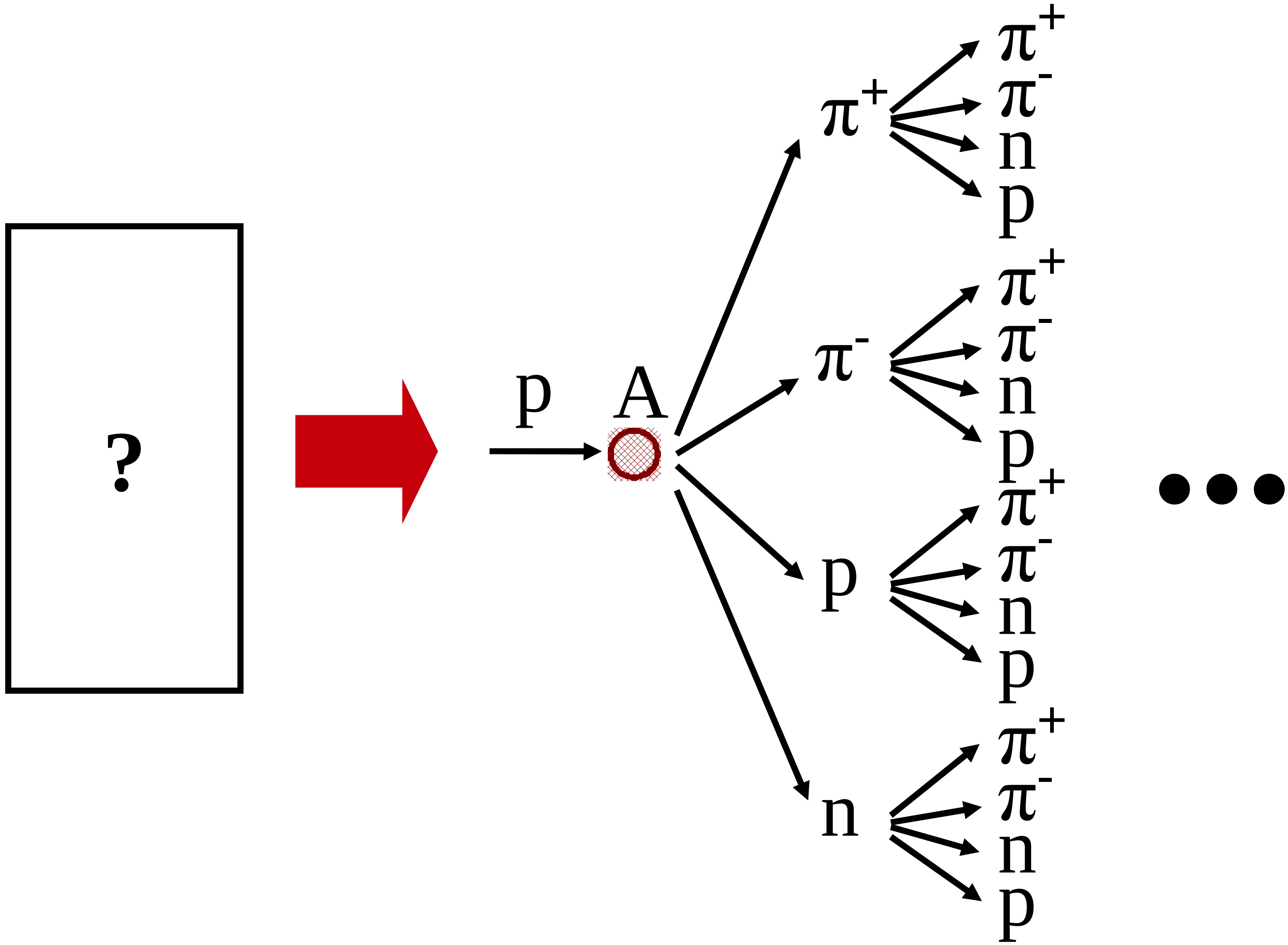
- Detailed description of geometry
- Geant4 or LSND cross-sections

Standalone

- Less detailed geometry
- LSND, FLUKA or Geant4 cross-sections
- Experimental cross-sections

Give consistent results


?
p
A
π+
π-
p
n

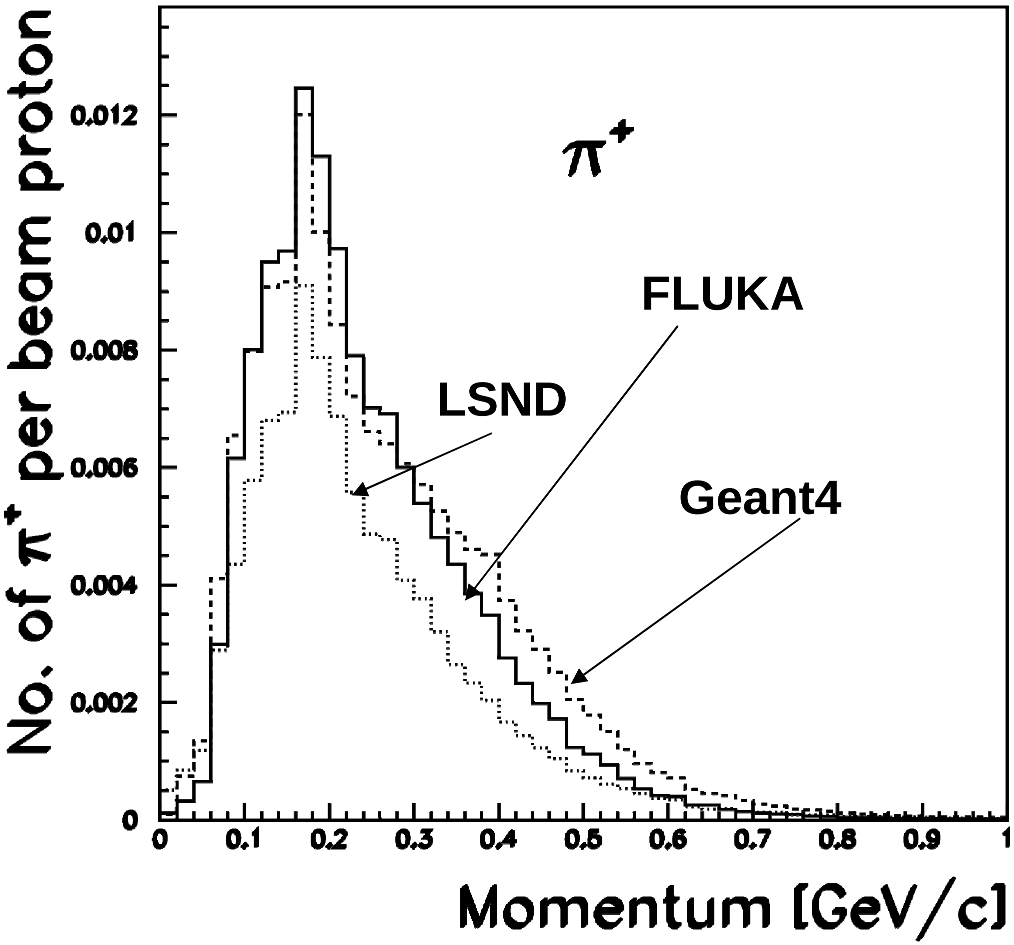

?
p
A
π^+
π^-
p
n
π^+
π^-
n
p
•••

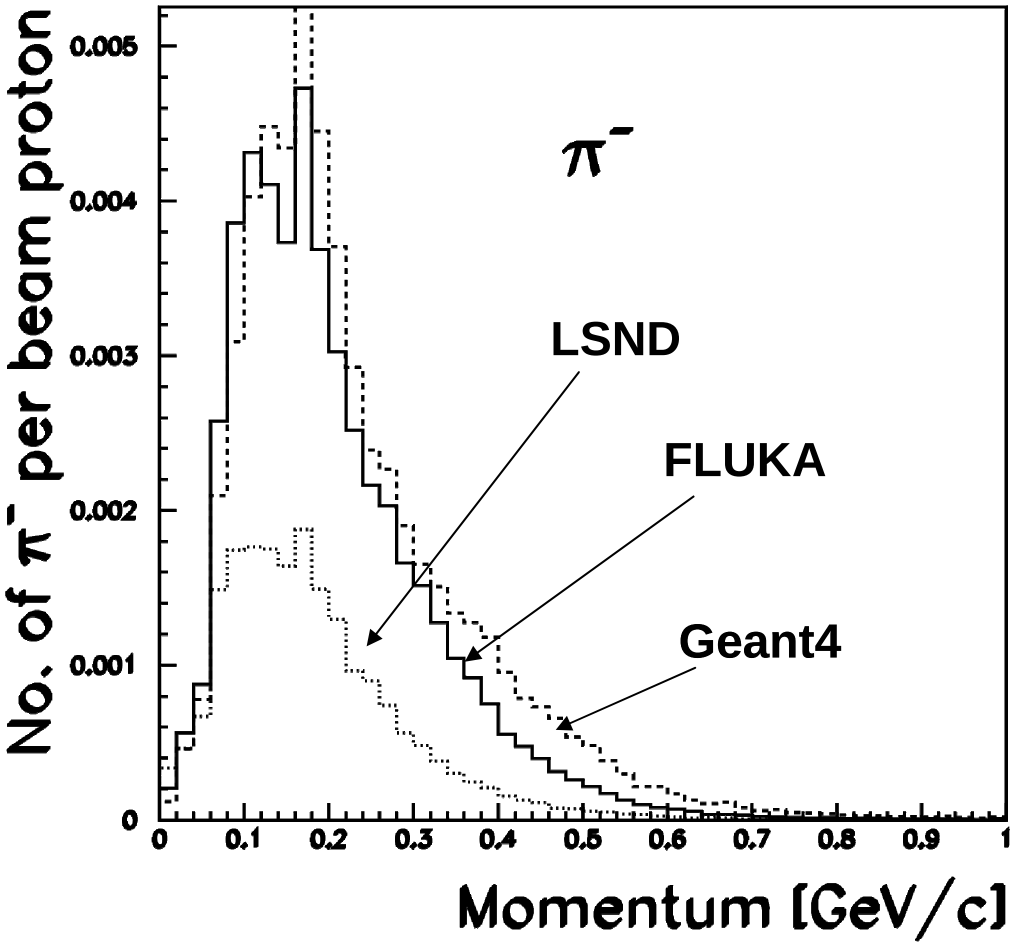
PRETTY COMPLICATED TASK

Need differential pion production cross-sections:

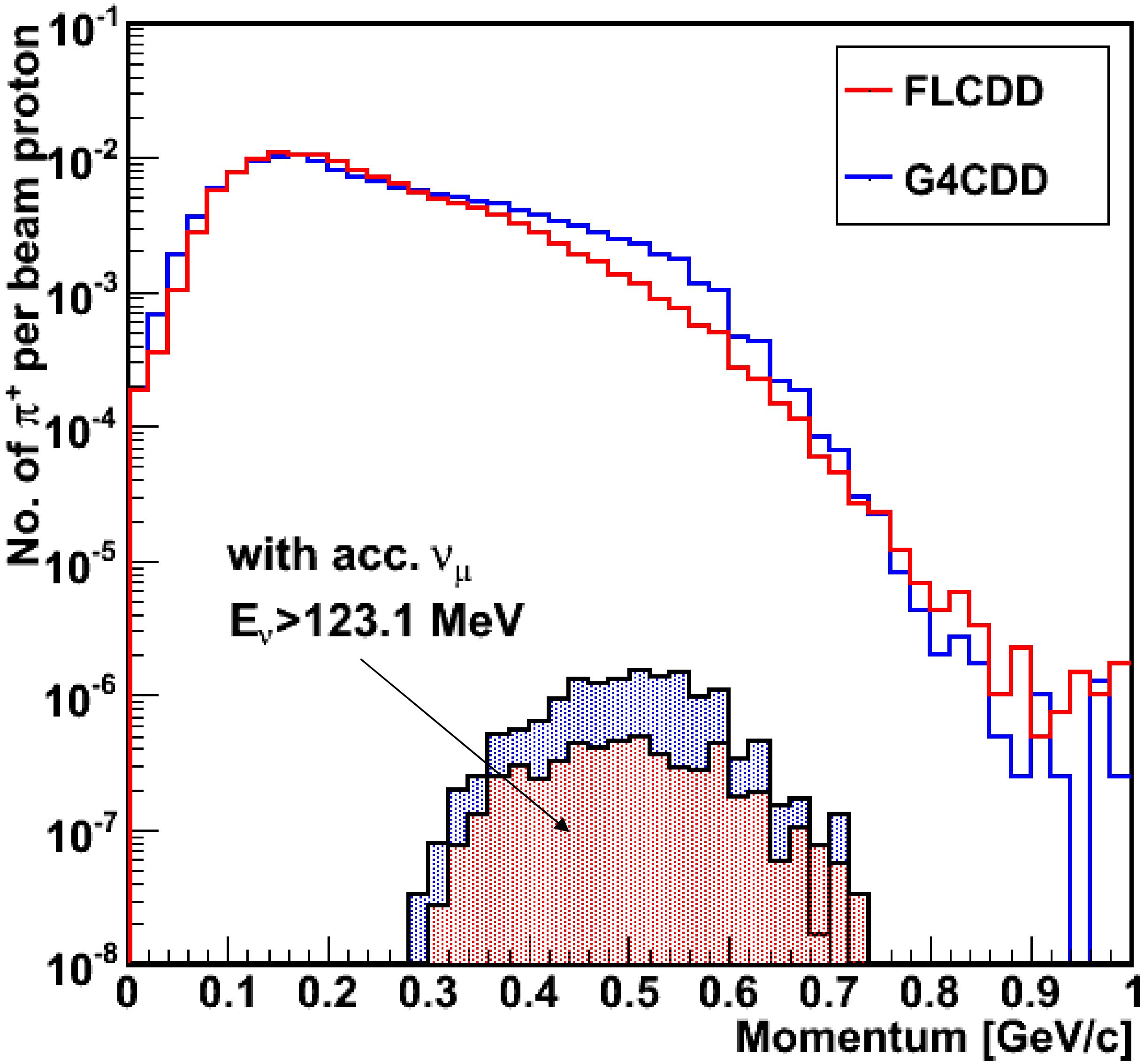
- of p, n, π^+,π^-
- on H_2O, Fe, Cu, Al, Mo, Air
- as a function of projectile momentum

Pions from different models

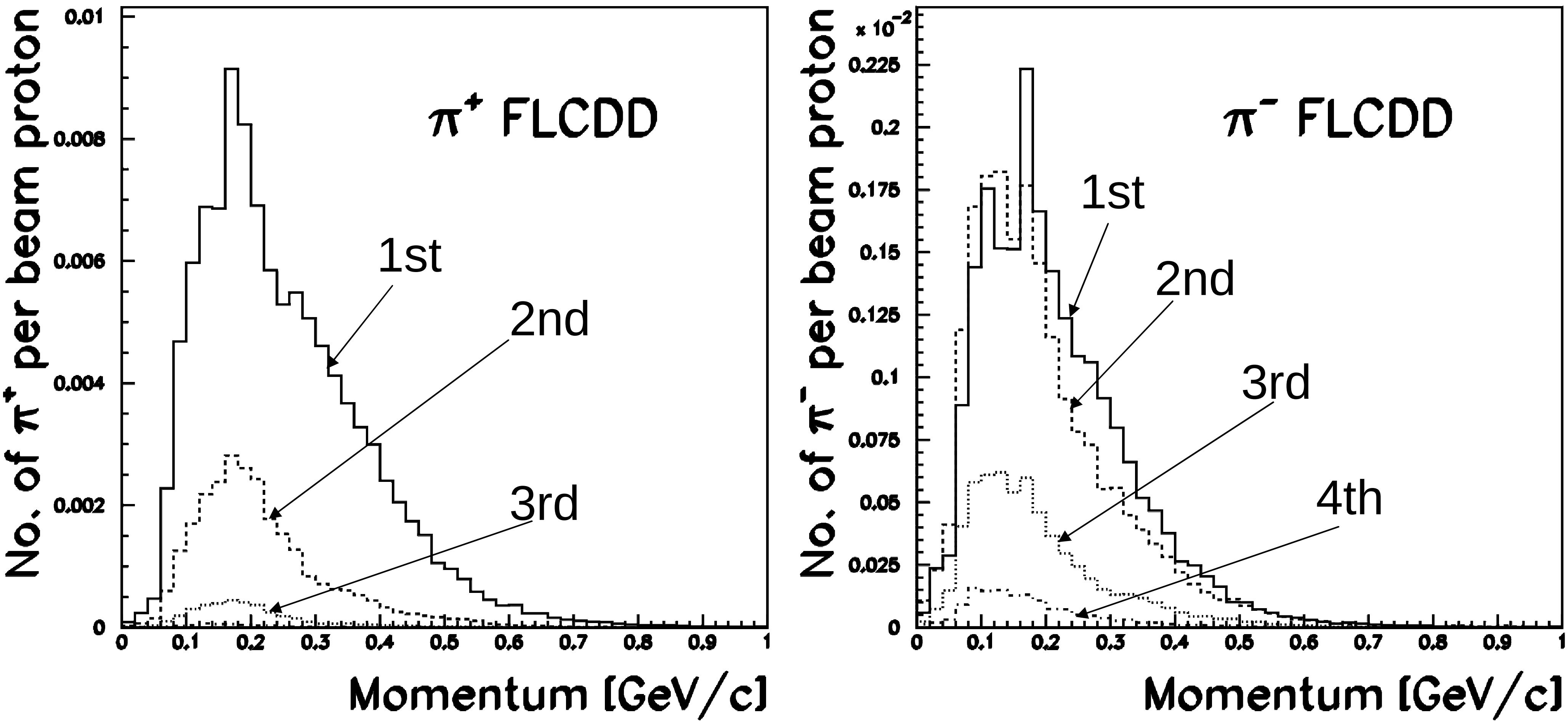




Pion momentum spectra

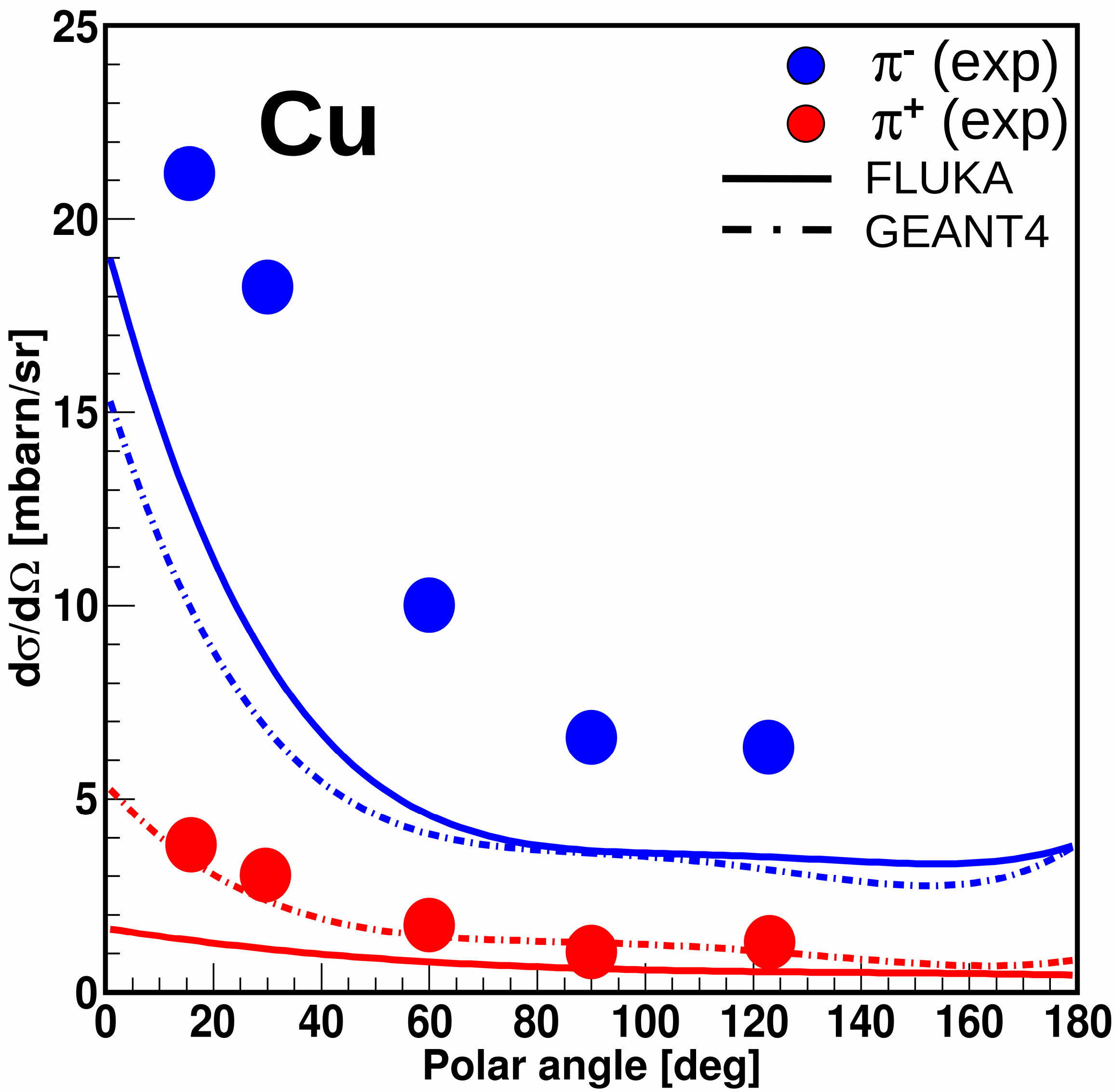


Pion generations



Pion production by 600 MeV neutrons

K.O. Oganesian, JETP 54 (1968) 1273



HARP-CDP simulation results

	LSND published (1993-1995)
π^-/π^+	(0.12)
DAR $\bar{\nu}_\mu$ [ν/PoT/cm^2]	0.8×10^{-9}
DAR $\bar{\nu}_e$ [ν/PoT/cm^2]	0.65×10^{-12}

HARP-CDP simulation results

	LSND published (1993-1995)	LSND "emulation"
π^-/π^+	(0.12)	0.20
DAR $\bar{\nu}_\mu$ [ν/PoT/cm^2]	0.8×10^{-9}	0.60×10^{-9}
DAR $\bar{\nu}_e$ [ν/PoT/cm^2]	0.65×10^{-12}	0.59×10^{-12}

HARP-CDP simulation results

	LSND published (1993-1995)	LSND "emulation"	Geant4 + Exp. data
π^-/π^+	(0.12)	0.20	0.36
DAR $\bar{\nu}_\mu$ [ν/PoT/cm^2]	0.8×10^{-9}	0.60×10^{-9}	0.78×10^{-9}
DAR $\bar{\nu}_e$ [ν/PoT/cm^2]	0.65×10^{-12}	0.59×10^{-12}	0.96×10^{-12}

HARP-CDP simulation results

	LSND published (1993-1995)	LSND "emulation"	Geant4 + Exp. data	FLUKA + Exp. data
π^- / π^+	(0.12)	0.20	0.36	0.34
DAR $\bar{\nu}_\mu$ [ν/PoT/cm^2]	0.8×10^{-9}	0.60×10^{-9}	0.78×10^{-9}	0.76×10^{-9}
DAR $\bar{\nu}_e$ [ν/PoT/cm^2]	0.65×10^{-12}	0.59×10^{-12}	0.96×10^{-12}	0.88×10^{-12}

Background I (genuine $\bar{\nu}_e$)

LSND published	HARP-CDP conjecture
19.5 +/- 3.9	30.6 +/- 8.8

Background II (fake $\bar{\nu}_e$)

Reaction	Background II type	No. events	
		LSND published	HARP–CDP conjecture
$\bar{\nu}_\mu$ p $\rightarrow \mu^+$ n			
	$T_\mu < 3$ MeV	8.2	10.8 ± 8.0
ν_μ ^{12}C $\rightarrow \mu^-$ ^{12}N			
	^{12}N*, $T_\mu < 3$ MeV,	1.4	1.8 ± 1.8
	μ^- capture	–	0.2 ± 0.2
$\bar{\nu}_\mu$ ^{12}C $\rightarrow \mu^+$ ^{12}B			
	$T_\mu < 3$ MeV	0.4	0.5 ± 0.5
Otherwise missed muon			
		0.4 ± 0.14	0.4 ± 0.14
$\mu^- \rightarrow$ e$^-$ $\bar{\nu}_e$ ν_μ, $\pi^- \rightarrow$ e$^-$ $\bar{\nu}_e$			
	$\bar{\nu}_e$ events	0.1 ± 0.1	0.1 ± 0.1
SUM		10.5 ± 4.6	13.8 ± 8.2

LSND analysis strategy

1. "Primary electron"

Electron (positron, γ, proton, …) with $20 < E < 60$ MeV
No action within 12 µs before the event
No action within 8 µs after the event

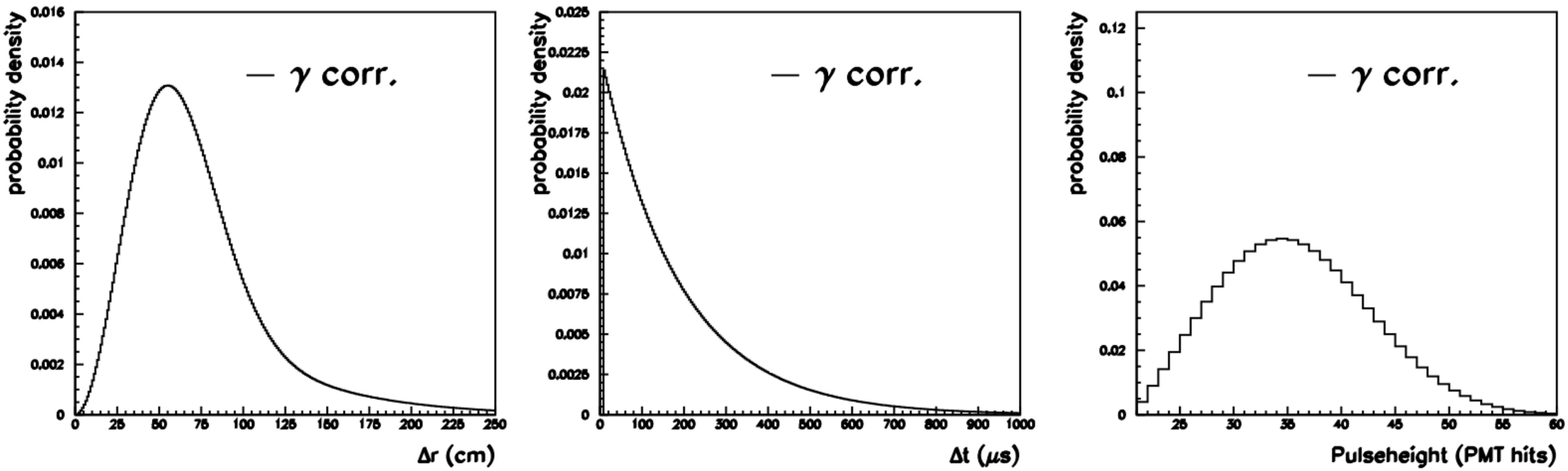
2. "R_γ criterion"

Filters out events with a "correlated γ" that is consistent with arising from neutron capture:
$n + p \rightarrow d + 2.2$ MeV γ

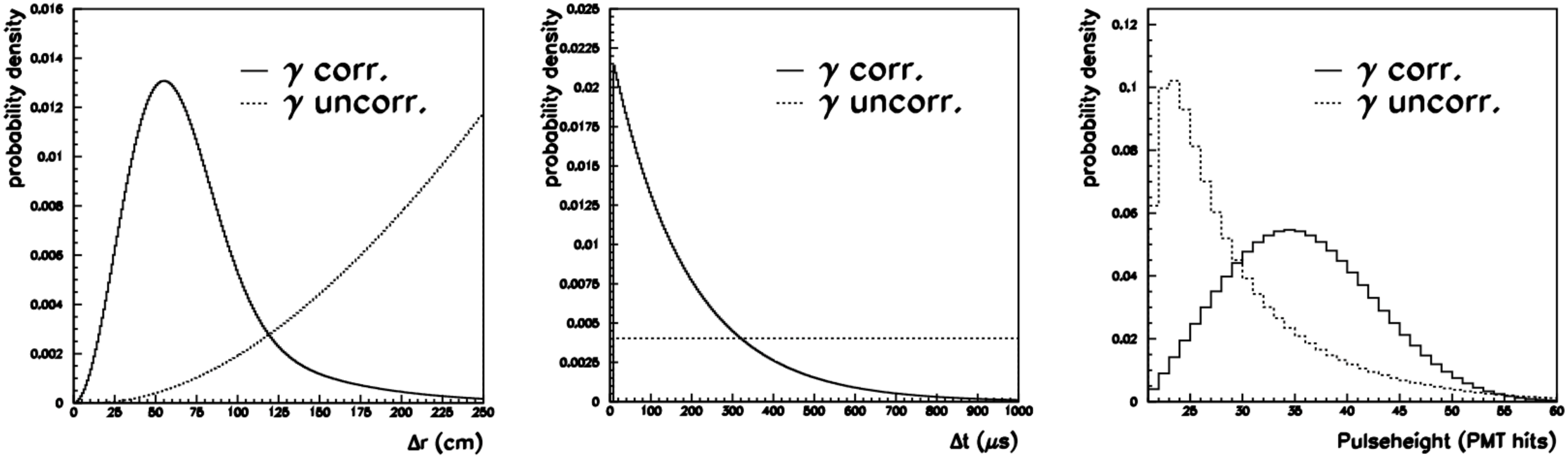
R_γ = Likelihood that the γ is correlated divided by the Likelhood that the γ is uncorrelated

Likelyhood = prob(Δr) × prob(Δt) × prob(pulseheight)

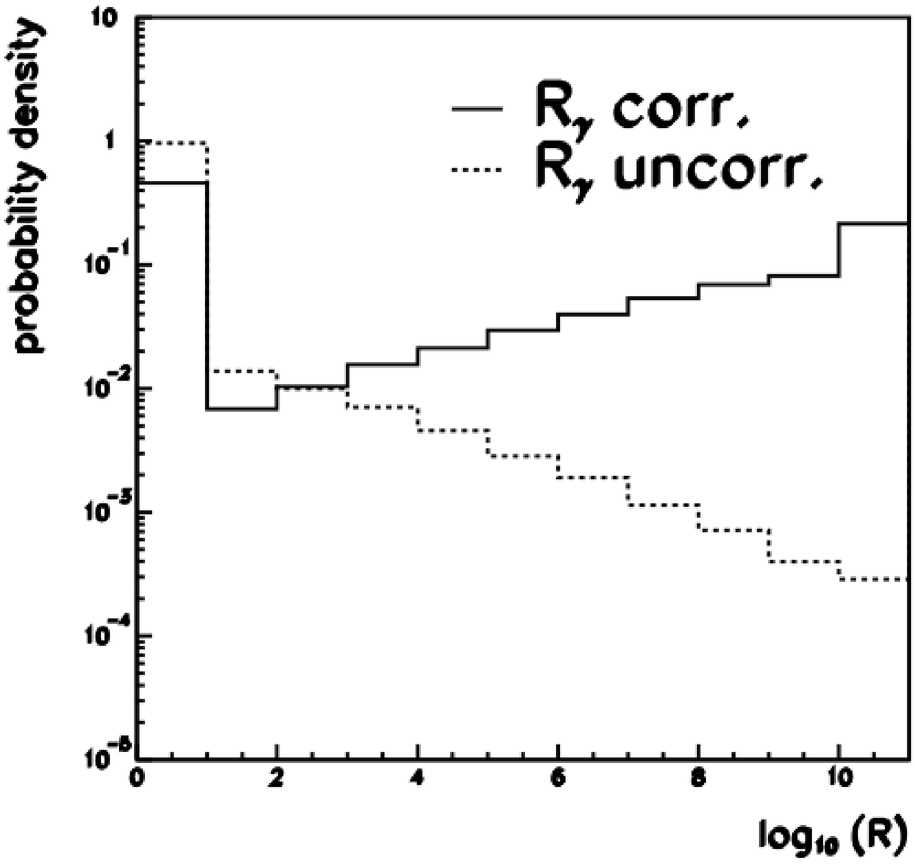
Correlated γ



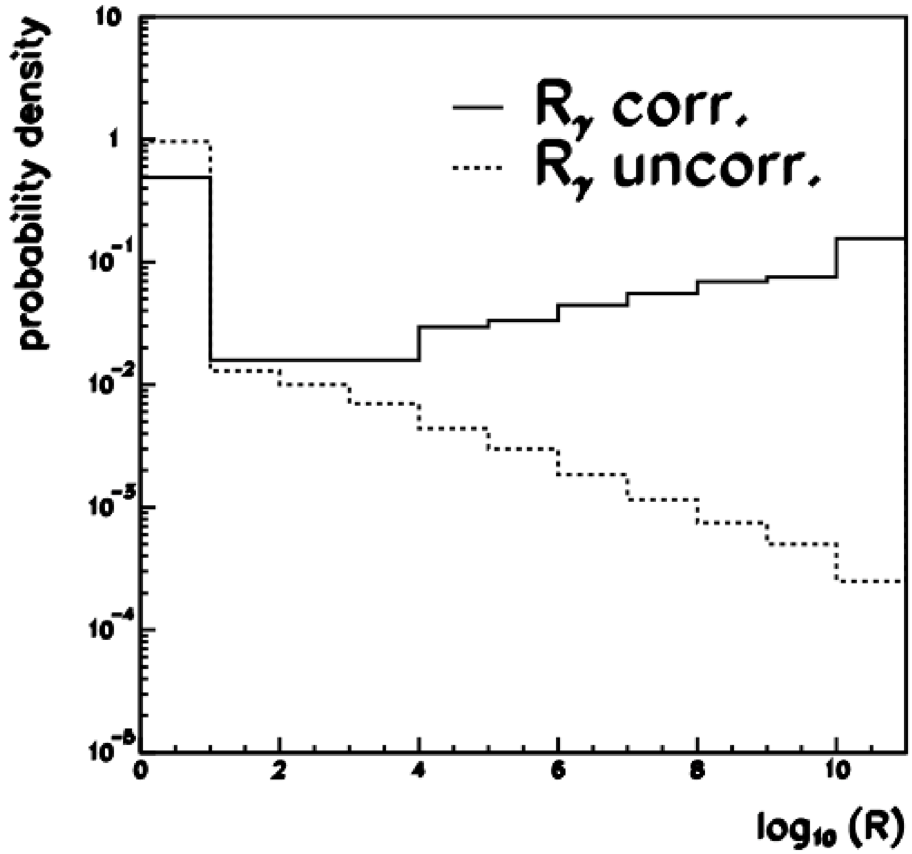
Correlated γ vs uncorrelated γ



R_γ

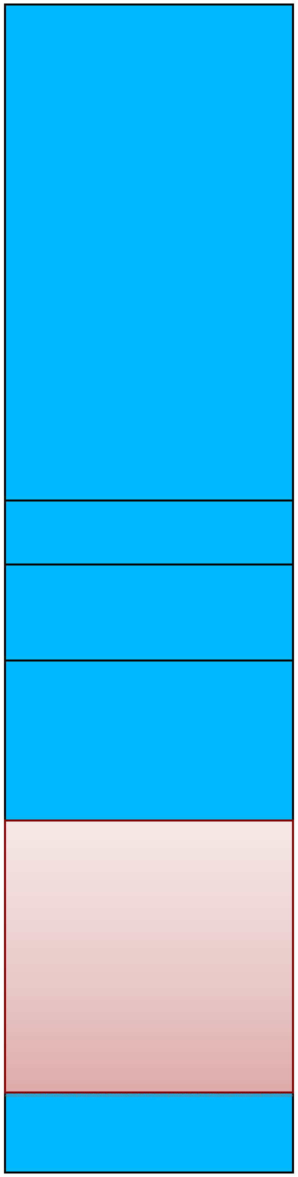


HARP-CDP simulation



LSND published

But something is missing



Total 2100 events

870 other (neutral-current events …)

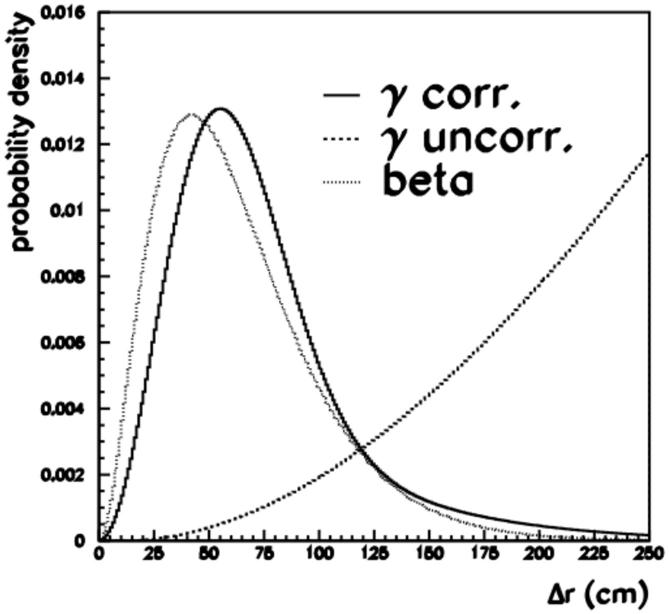
100 ν_μ with missed muon
150 ν_e elastic scattering

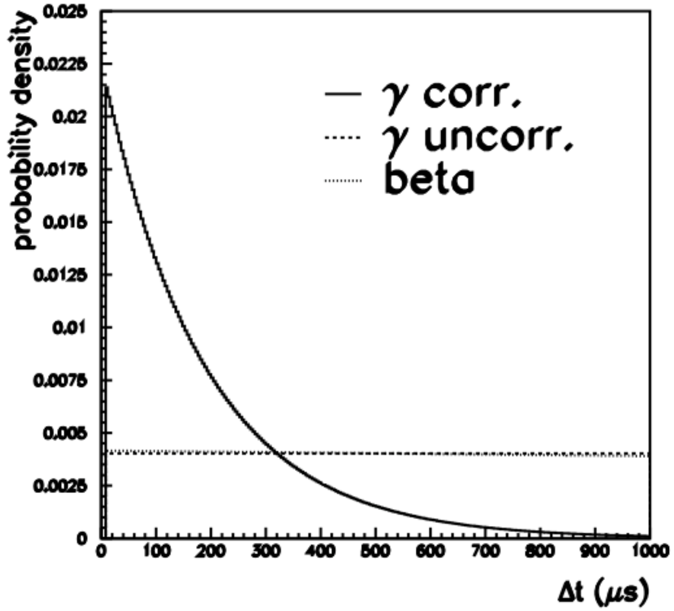
300 ν_e leading to $^{12}N^*$

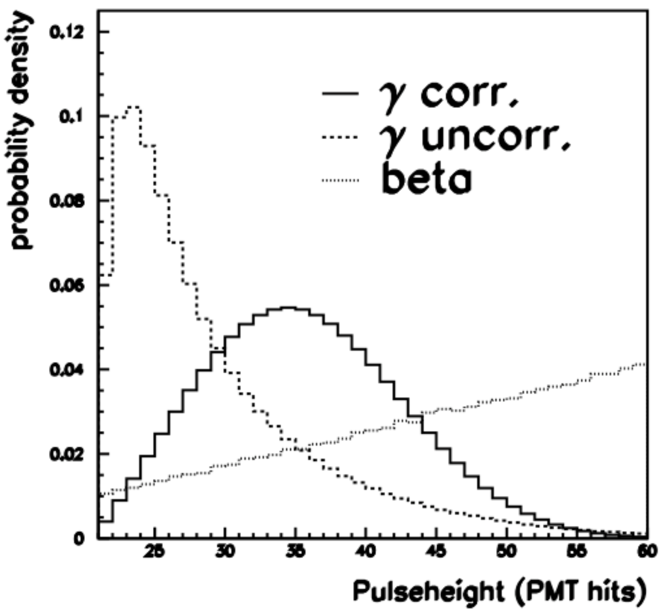
600 ν_e leading to $^{12}N_{gs}$ with subsequent beta decay

120 signal candidates

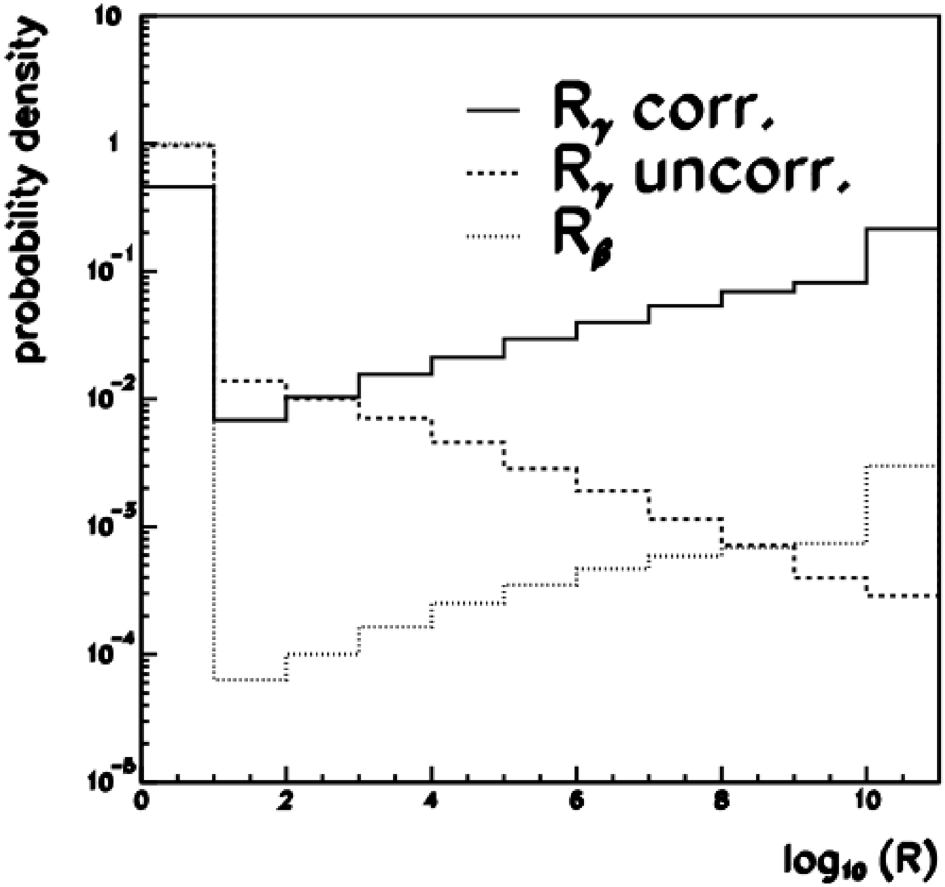
Correlated γ vs uncorrelated γ vs β



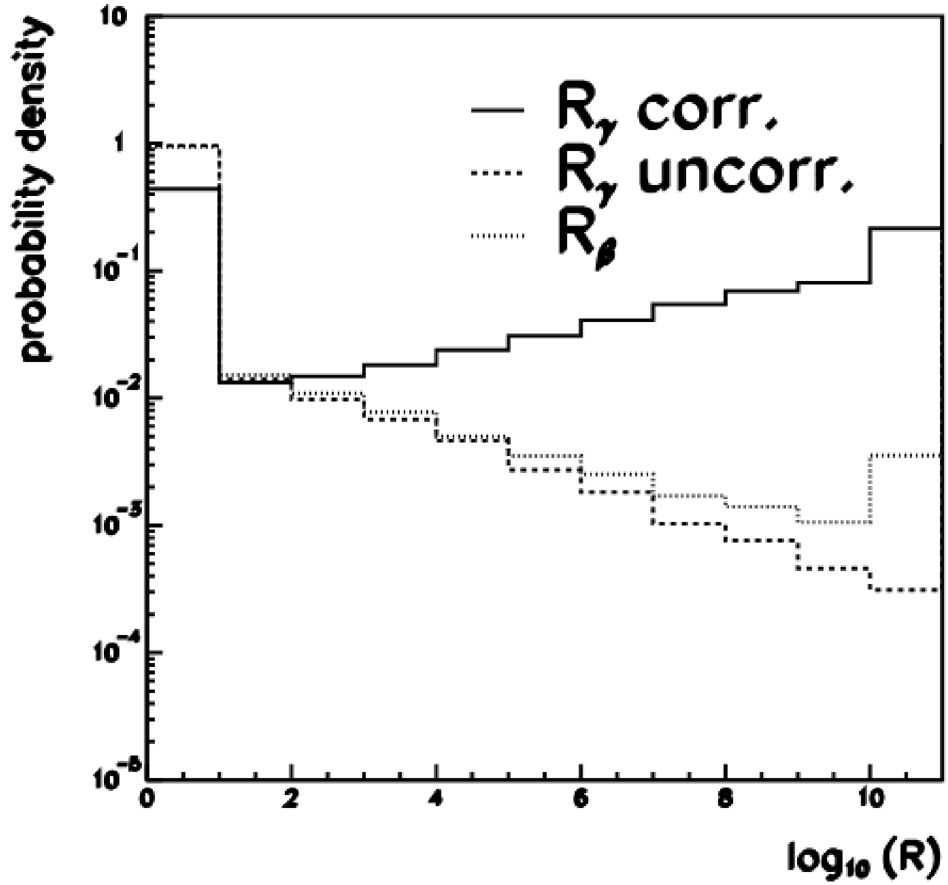




R_γ corr. vs R_γ uncorr. vs R_β



Without accidental γ’s



With accidental γ’s (1.1 kHz)

Signal significance

	LSND published	HARP–CDP conjecture
Beam excess	117.9 ± 22.4	110.0 ± 22.4
Background I	19.5 ± 3.9	30.6 ± 8.8
Background II	10.5 ± 4.6	13.8 ± 8.2
LSND anomaly	87.9 ± 23.2	65.6 ± 25.4
Significance	$3.8\,\sigma$	$2.6\,\sigma$

110.0 +/- 22.4 PRELIMINARY !

LSND's cross-checks

Reaction	Theor. uncertainty	Constrains	Comment
$\nu_e\ {}^{12}\mathrm{C} \to e^-\ {}^{12}\mathrm{N}_{gs}$	5%	ν_e from μ^+ DAR and all π^+ to 11%	'hard'
$\nu\ e \to \nu\ e$	1%	ν_e from μ^+ DAR and all π^+ to about 20%	nothing new
$\nu_\mu\ {}^{12}\mathrm{C} \to \mu^-\ {}^{12}\mathrm{N}_{gs}$	5%	$\nu_\mu > 123.7$ MeV and high-momentum DIF π^+ to 17%	'hard'
$\nu_\mu\ {}^{12}\mathrm{C} \to \mu^-\ X$ $+\ \bar{\nu}_\mu\ {}^{12}\mathrm{C} \to \mu^+\ X$ $+\ \bar{\nu}_\mu\ p \to \mu^+\ n$	factor of 2 (?) factor of 2 (?) 5%	Cross-section of $\nu_\mu\ {}^{12}\mathrm{C} \to \mu^-\ X$ to 17%	'hard'
$\nu_\mu {}^{12}\mathrm{C} \to \mu^-\ n\ X$ $+\ \bar{\nu}_\mu\ {}^{12}\mathrm{C} \to \mu^+\ n\ X$ $+\ \bar{\nu}_\mu\ p \to \mu^+\ n$	(?) (?)	$\bar{\nu}_\mu > 113.1$ MeV and high-momentum DIF π^- to 32%	'soft'
$\nu_\mu\ {}^{12}\mathrm{C} \to \mu^-\ n\ X$		$123.7 < E_\nu < 127.7$ MeV to 35%	'very soft'
$\bar{\nu}_\mu\ p \to \mu^+\ n$		$113.1 < E_\nu < 117.1$ MeV to 60%	'very soft'

Summary

- Independent simulation of the background to the LSND $\bar{\nu}_e$ signal carried out
- FLUKA and Geant4 cross-sections used as starting point, adjusted by HARP-CDP data and experimental pion production by neutrons
- Re-analysis of the fraction of events with a correlated neutron carried out
- The 3.8 σ significance of the LSND anomaly reduces (preliminarily) to a 2.6 σ significance

The HARP-CDP group

A. Bolshakova, I. Boyko, G. Chelkov, D. Dedovich,

A. Elagin, D. Emelyanov, M. Gostkin, A. Guskov,

Z. Kroumchtein, Yu. Nefedov, K. Nikolaev,

A. Zhemchugov, F. Dydak, J. Wotschack,

B. De Min, V. Ammosov , V. Gapienko,

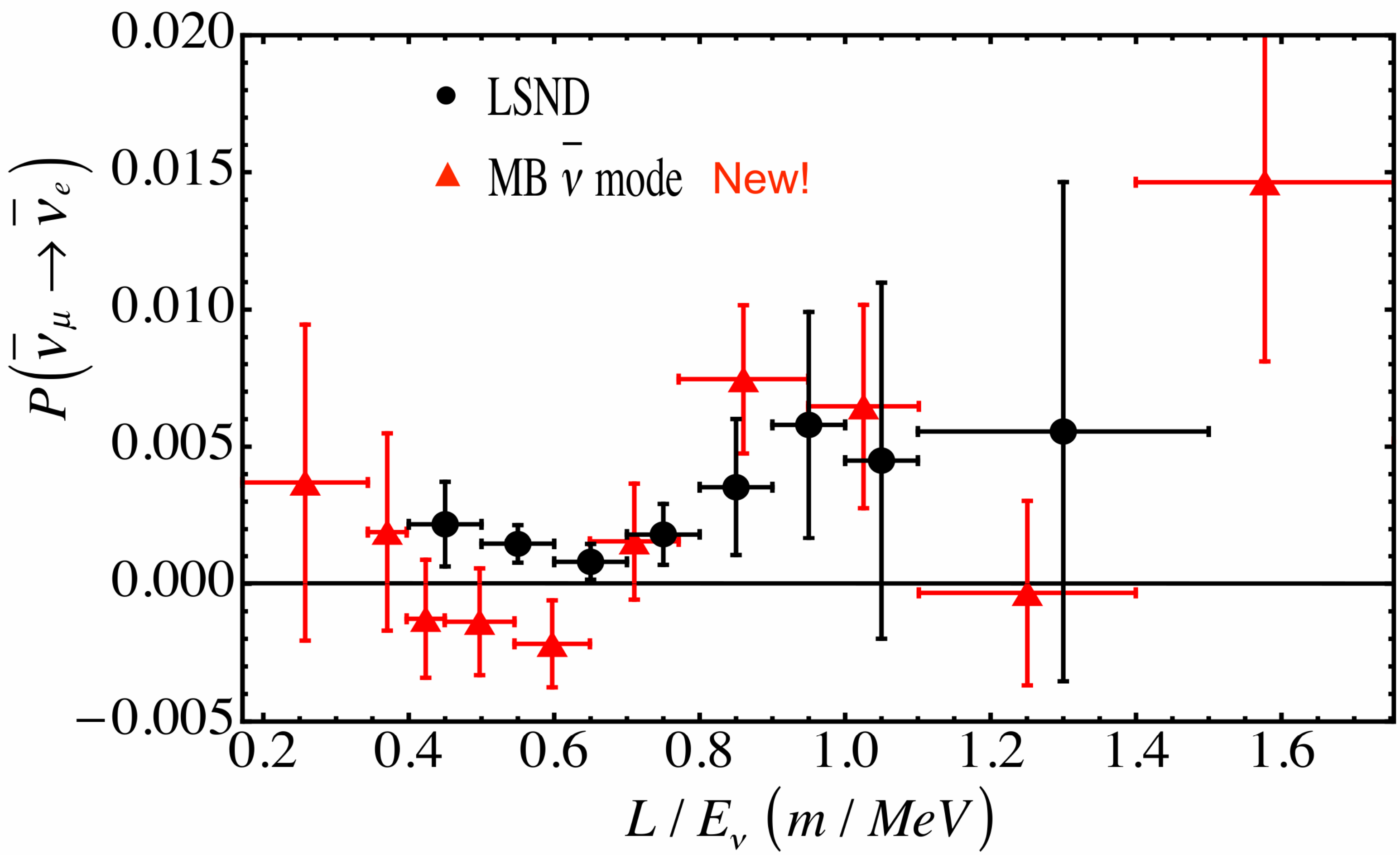
V. Koreshev, A. Semak, Yu. Sviridov, E. Usenko,

V. Zaets

Backup

Test by MiniBooNE

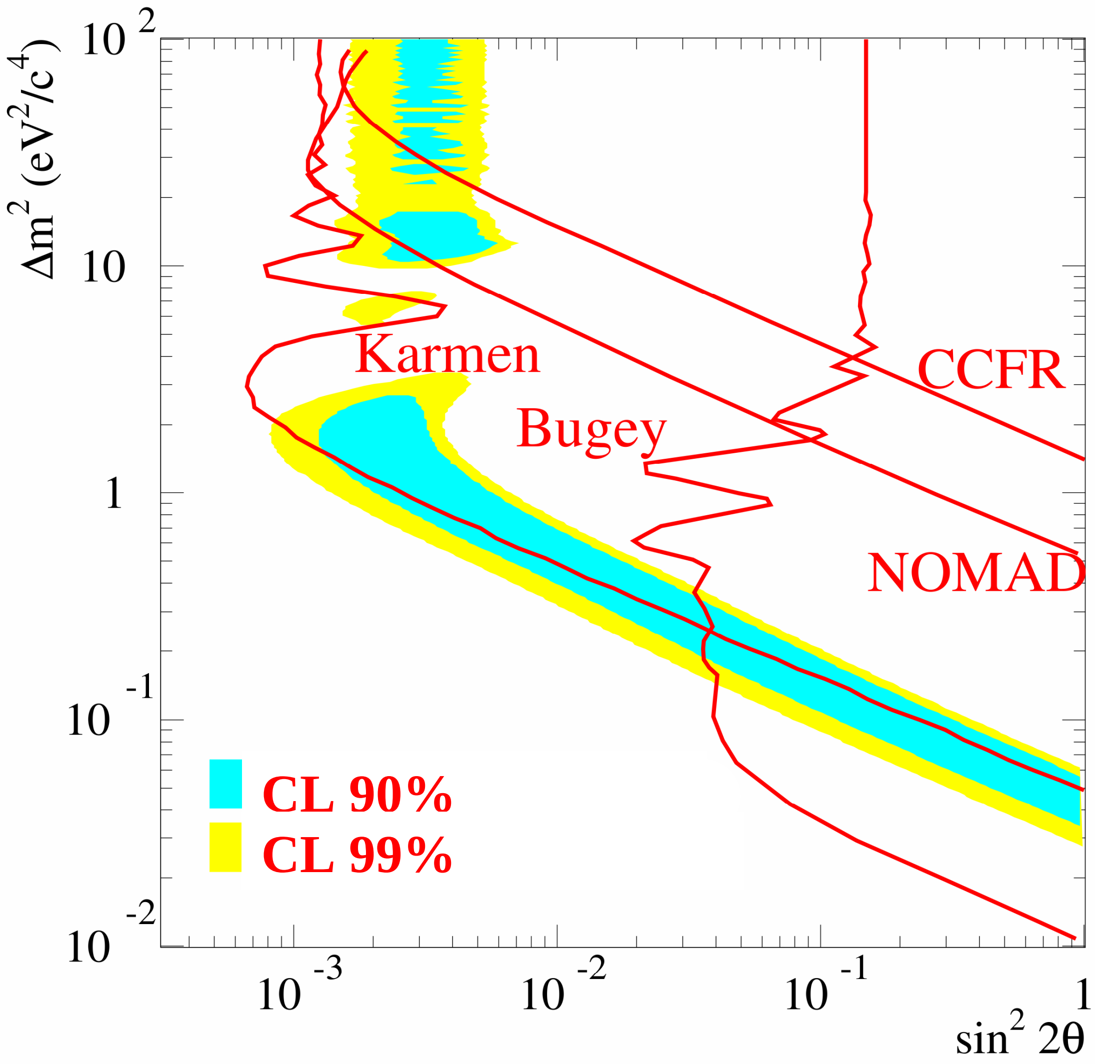
Direct MiniBooNE-LSND Comparison of $\bar{\nu}$ Data



G.Mills, ICHEP2010

The "LSND anomaly"

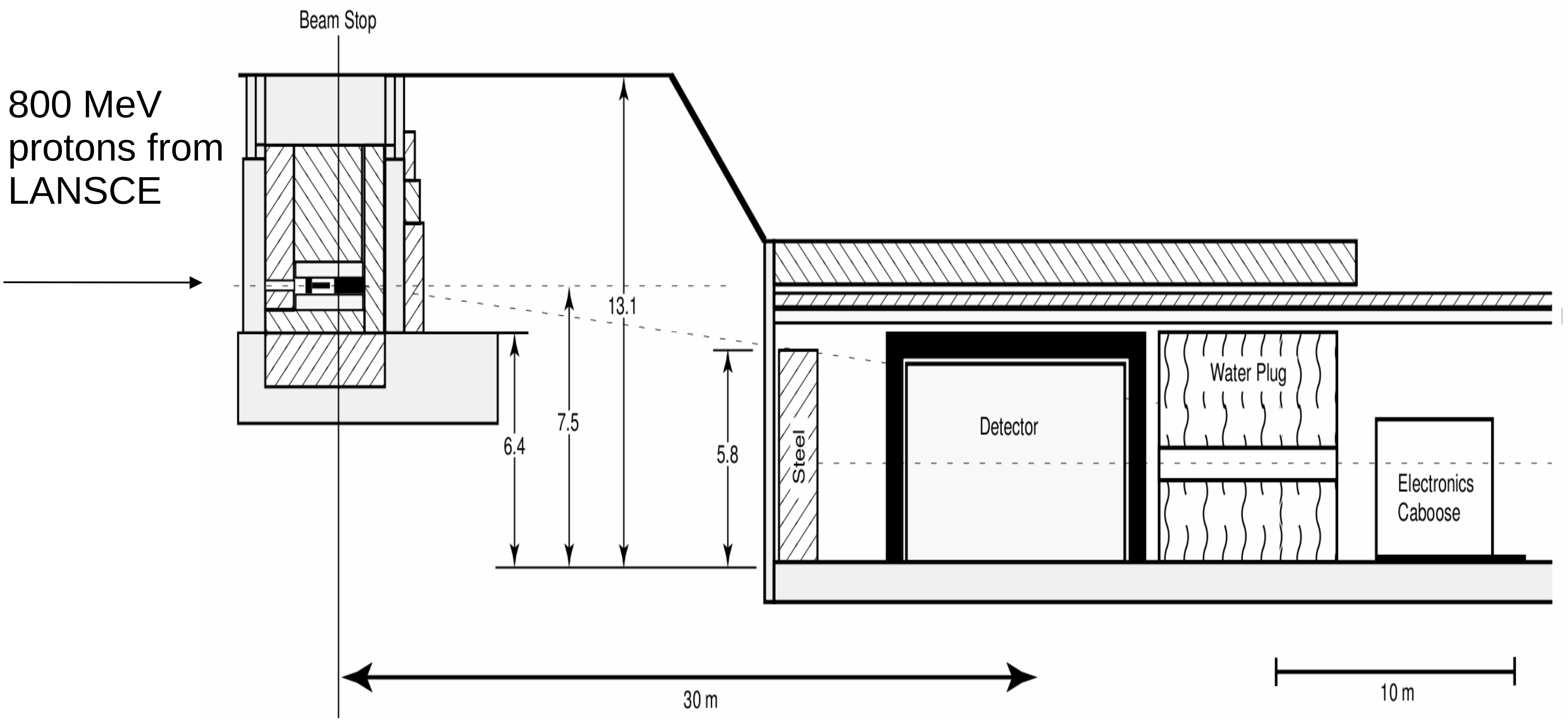
A. Aguilar et al.,
PRD64 (2001) 112007



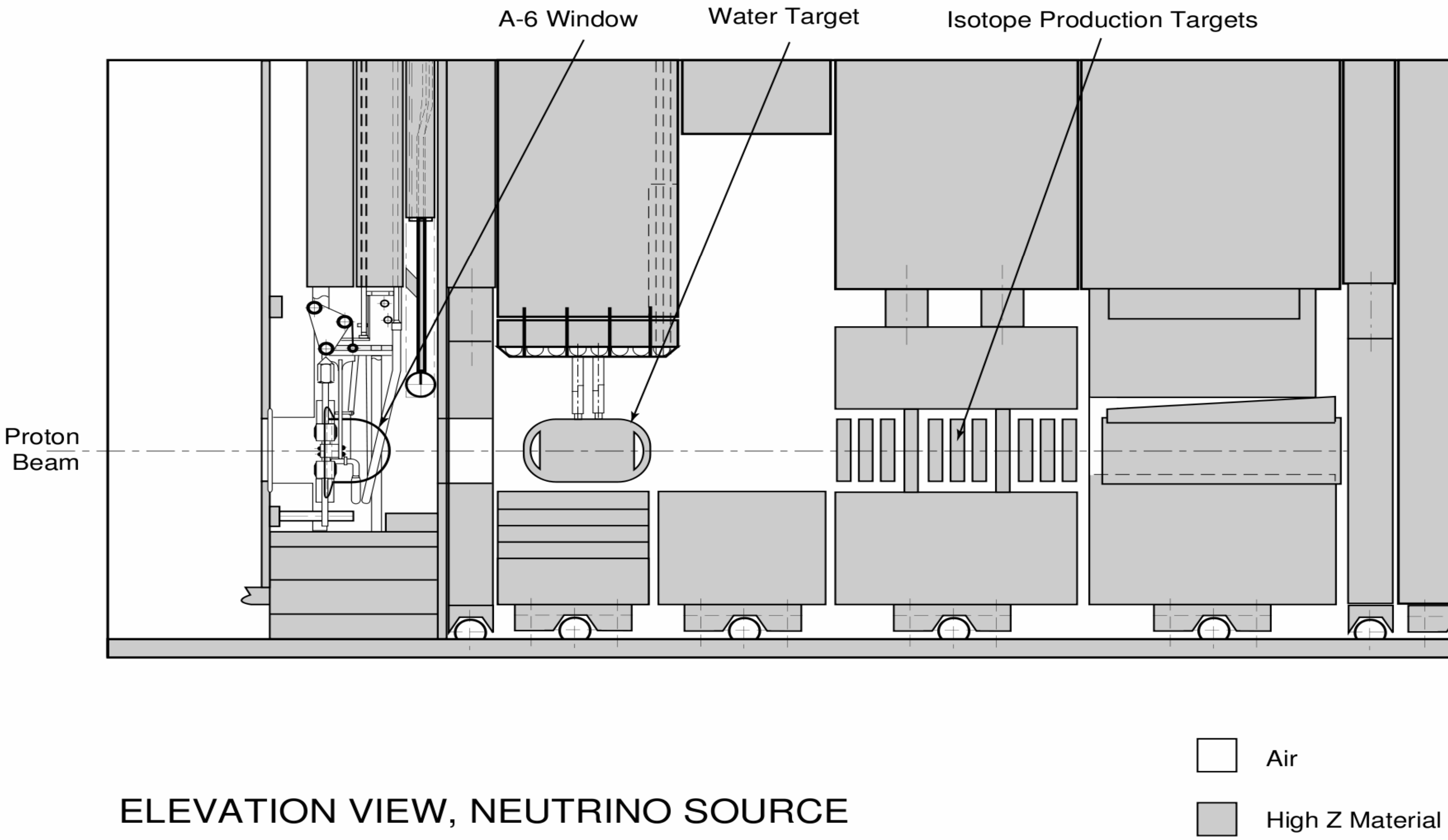
Δm^2 in the range of 0.2 – 10 eV^2

The LSND experiment

800 MeV protons from LANSCE



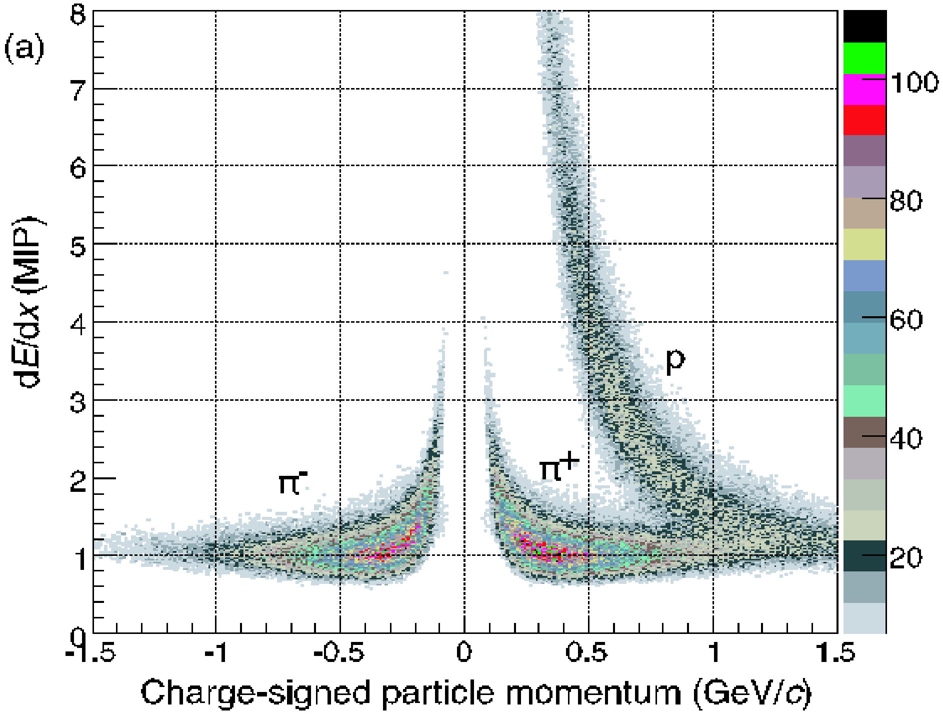
The LSND neutrino source (side view)

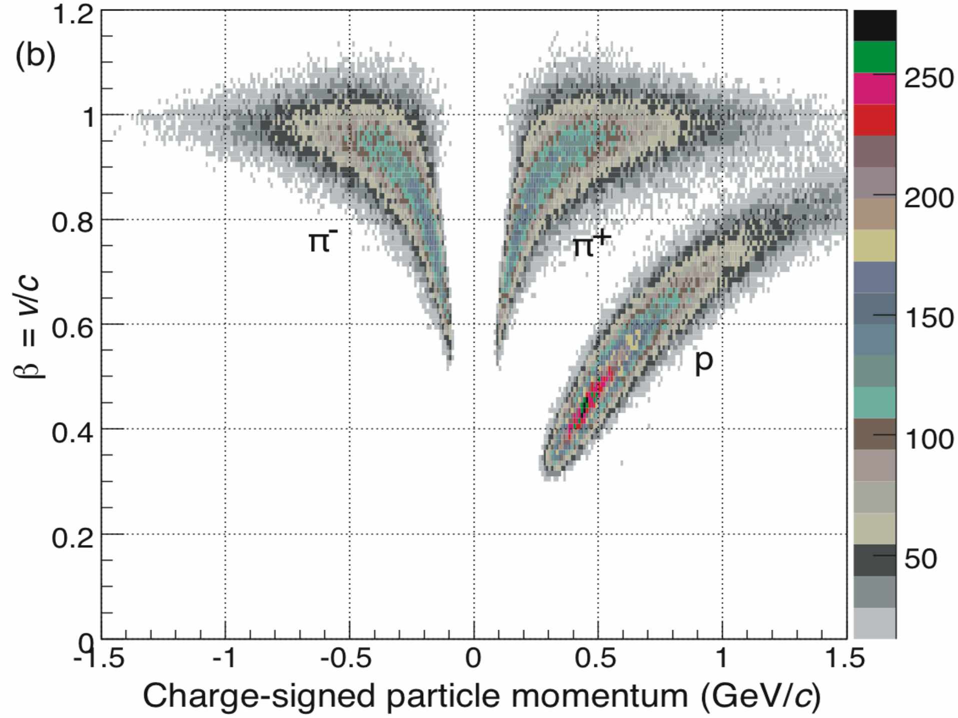


C.Athanassopoulos et al., NIM A388 (1997) 149-172

Geometry of 1993-1995

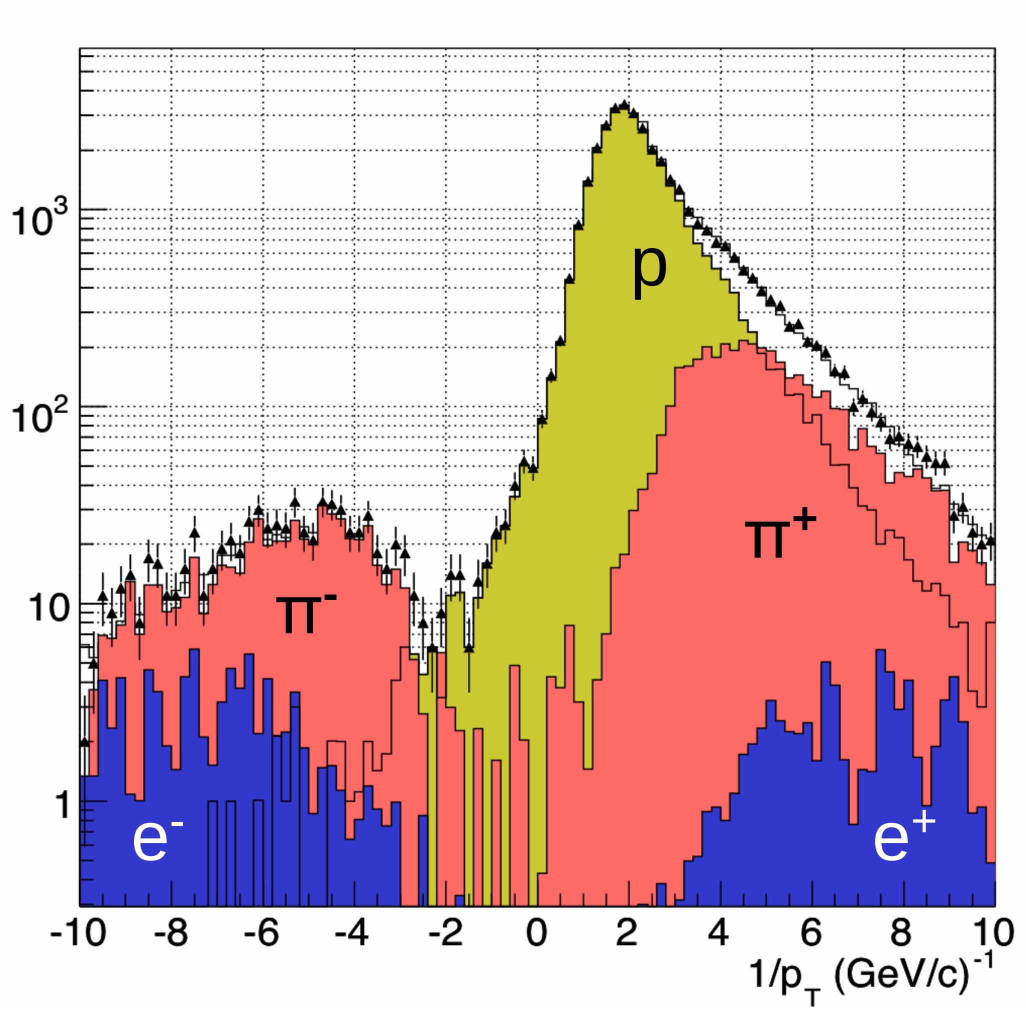
The HARP experiment





Good particle identification by combining d*E*/d*x* from TPC and TOF from RPCs

The HARP experiment



Allows to check an important ingredient of the LSND background: the production of π^- by 1.5 GeV/c protons